EVALUATION OF SHALLOW LAND BURIAL OF DEFUELED NAVAL REACTOR COMPARTMENT PACKAGES AT HANFORD
(protection of the inadvertent intruder and the environment from radioactivity contained in irradiated structure)

Appendix B

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1. PURPOSE

The purpose of Appendix B is to demonstrate that the disposal of Naval Reactor Compartments at the 218-E-12B Low Level Waste Burial Ground at Hanford, WA, meets the performance objectives for intruder and environmental protection under 10CFR61 for shallow land burial.

2. BACKGROUND

2.1 Location and Nature of Reactor Compartment Radioactivity

Naval Reactor Compartment Disposal Packages encompass the Reactor Compartment, that portion of a ship which supports and contains the ship's nuclear reactor plant. The reactor plant consists of the reactor vessel and associated piping and components that transfer heat from the reactor vessel and generate steam to propel the ship. Figure B-1 provides a simplified layout of a naval reactor compartment. Figure B-2 provides a simplified cross section of the reactor vessel itself. When the reactor plant is operational, reactor fuel is held within the reactor vessel internal structure shown. Neutrons escaping the fuel and adjacent areas activate the reactor vessel internal structure and to a smaller extent the interior the reactor vessel and surrounding areas. Certain longer lived radionuclides are of primary significance in naval reactor plants due to a combination of half-life, type and energy of decay radiation produced, and quantity within the reactor vessel. Table B-1 provides relevant properties of these principle radionuclides. Reactor vessel internal structure and operational life varies from ship to ship with a resulting variance in activity. Once the reactor has been defueled and inactivated, activity ranges are typical of that presented in Table B-1. Additional analysis of longer lived radioactivity within the reactor vessel can be found in Appendix D.

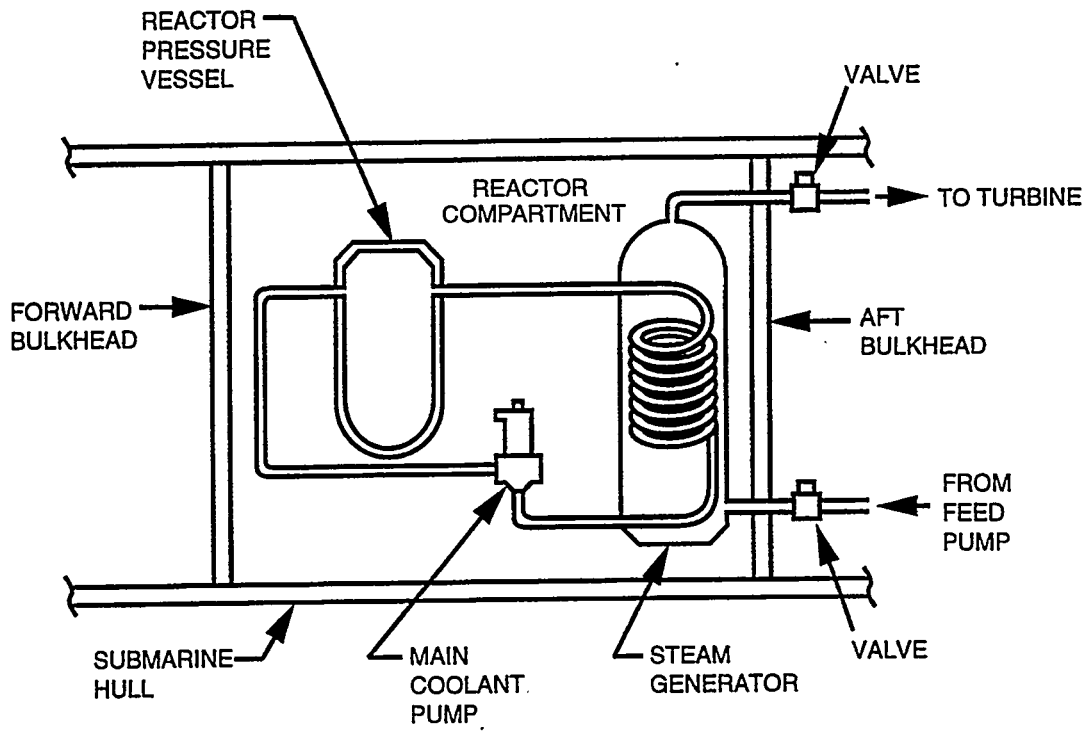

Figure B-1 Reactor Compartment Layout (conceptual)

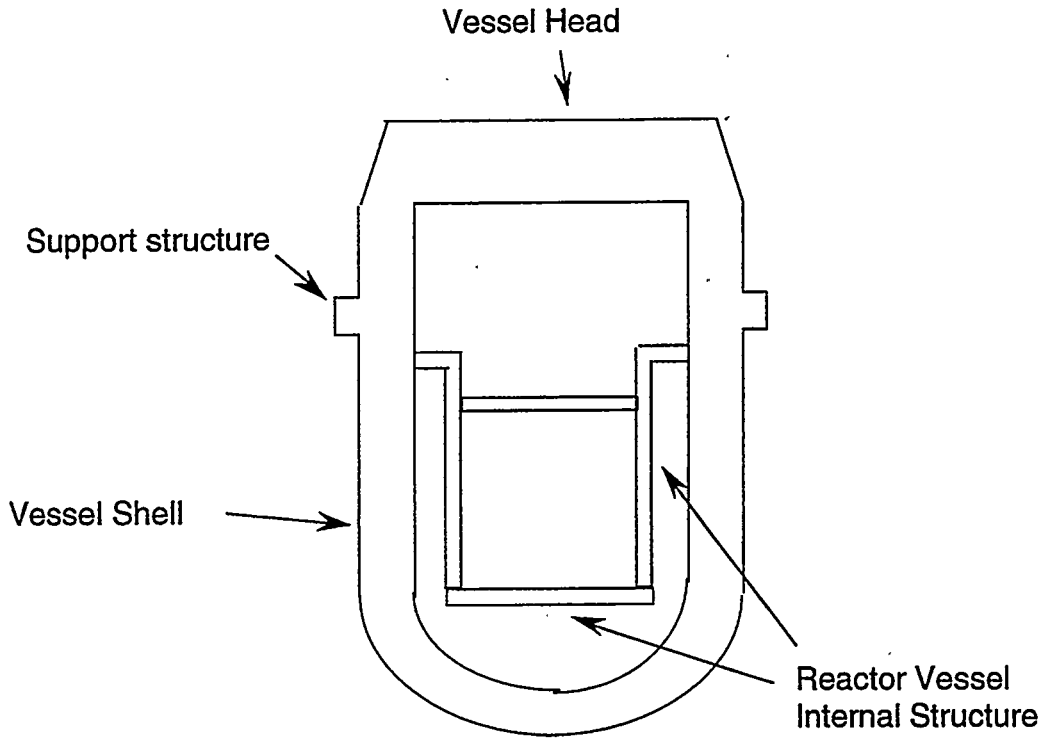

Figure B-2 Reactor Vessel (typical)

Radionuclide	Radiation	Gamma Ray Energy per Disintegration	Half-life (years)	Typical Quantity in Reactor Compartments (curies)
carbon-14	beta particle	no gamma	5730	0.5 - 15
nickel-59	X-ray	no gamma. X-ray energy typically less than 0.01 MeV.	75,000	100 - 300
nickel-63	beta particle	no gamma	100	10,000 - 30,000
niobium-94	beta particle and gamma ray	two in-series gammas: 0.87 MeV (100%) 0.70 MeV (100%)	20,300	0.5 - 1
technetium-99	beta particle	no gamma	213,000	0.01 - 0.03

Table B-1 Significant Longer Lived Reactor Compartment Radionuclides

3. EVALUATION OF REACTOR COMPARTMENTS

3.1 Structure and shielding

Reactor compartments are by nature massive, robust, integrated structures composed of interconnected structural containment walls, foundations, components, piping, and shielding, including the reactor vessel and its internals. These compartments, along with portions of adjacent spaces and tanks are sealed to form the disposal package by utilization of existing external ships structure such as submarine pressure hull and placement of external bulkheads and covers. Figure B-3 shows the external appearance of a typical submarine reactor compartment disposal package. The proposed LOS ANGELES and OHIO class packages would be somewhat larger than the current pre-LOS ANGELES reactor compartment packages but the basic configuration would remain the same. Submarine hulls are typically very high tensile strength (HY-80) alloy about two inches thick. External bulkheads would be installed for disposal and would be 3/4 inch steel plate.

T-stiffeners may project out from the plate as shown. Inside the end bulkheads, additional ship's bulkheads of at least 1/2 inch thickness steel enclose the reactor compartment. Entry to the reactor compartment would be blocked by the external bulkheads and one or more secured accesses. Ship's hull penetrations would be covered by welded plates.. Hull penetrations leading directly into the reactor compartment fall within two groups (1) holes 6 inches or less in diameter that would be covered by a minimum of 1/2 inch thick welded blanks which overlap the hull surface and (2) larger access cuts through the hull that would be restored with much thicker material, typically the same section of hull originally removed to create the access. High strength (HS/HT) carbon steel is typically found in ship's bulkheads and structure installed for disposal.

Figure B-4 shows the external appearance of the conceptual cruiser reactor compartment disposal package. Cruiser reactor compartments are located deep inside the ship. Existing ship's inner bottom structure would be incorporated into the foundation of the disposal package with high strength carbon steel containment structure installed up the side and over the top to form the package. This containment structure would be a minimum of 1.25 inches thick at the top of the package, and thicker at the bottom for added support. Inside this containment structure, an existing ship's 0.625 inch thick high strength carbon. steel bulkhead would enclose the reactor compartment which has the same shape as the package. Support fixtures would be added to aid in transporting the package. The resulting disposal package would be as robust as the disposal packages for submarines.

Reactor plant design is similar between cruisers and submarines. The reactor vessel internal structure is nested inside the vessel and is composed typically of Inconel Alloy 600. An enclosed shield water tank structure of several inches of combined metal thickness surrounds most of the reactor vessel. The reactor vessel is constructed of alloy steels and varies in thickness from a minimum of approximately 3 inches to over 6 inches. The combined thickness of the reactor vessel and surrounding tank structure result in a minimum of about one half foot of steel preventing access to the reactor vessel internal structure.

Existing lead shielding in and around the reactor compartment provides gamma attenuation. The ship's bulkheads which enclose the reactor compartment are lined with solid lead shielding, bonded or cast in place and covered by 0.25 inch minimum metal canning plate. Additional canned lead is placed in various locations on reactor plant components and at various locations around the inside of the ship's hull where this structure forms part of the reactor compartment. Existing polyethylene shielding, for neutron attenuation, is also attached on the ship's bulkheads and on the reactor vessel itself.

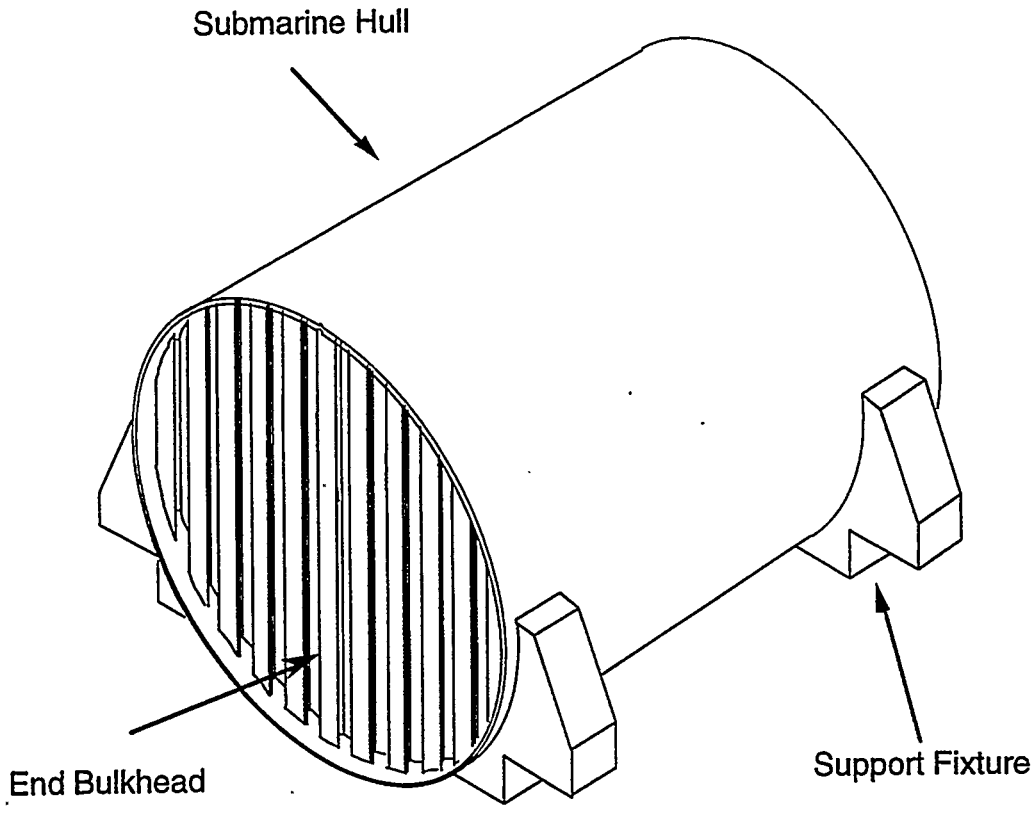

Figure B-3 Typical Submarine Reactor Compartment

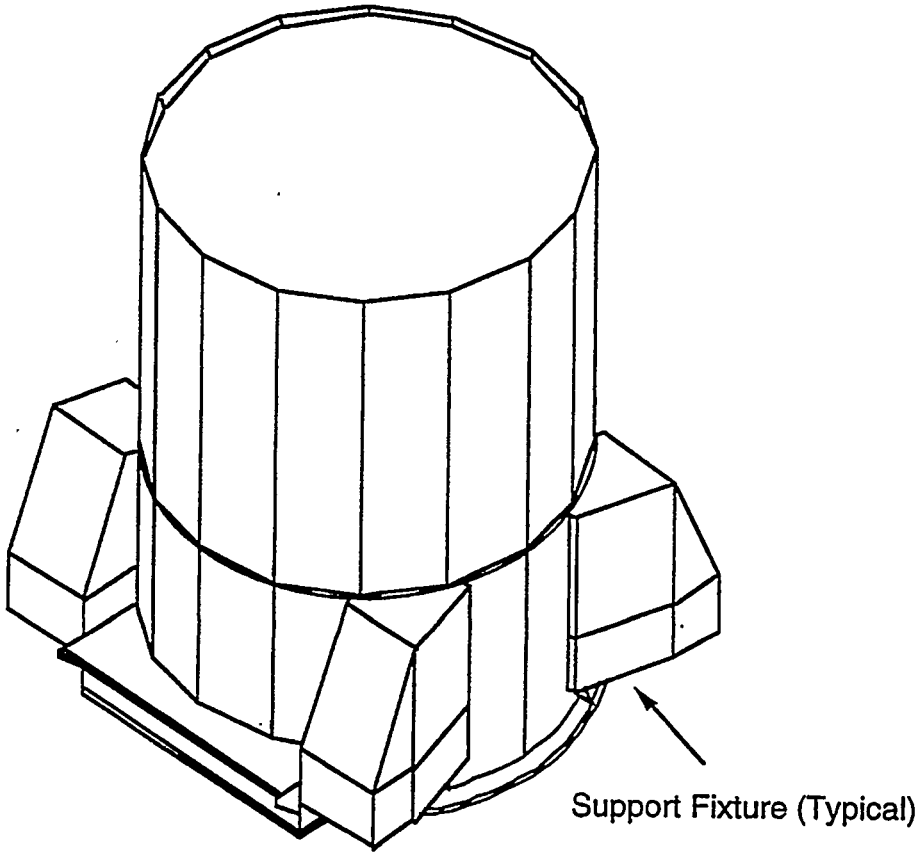

Figure B-4 Conceptual Cruiser Reactor Compartment

3.2 Disposal Site

The Hanford Site is a 560 square mile (1450 square kilometer), mostly undisturbed area of relatively flat shrub-steppe desert lying within the Pasco Basin of the Columbia Plateau, a semi-arid region in the rain shadow of the Cascade Mountain Range.

Pre-LOS ANGELES class reactor compartments are currently being disposed of at the 218-E-12B burial ground of the Hanford Site. This location is also the preferred alternative for disposal of cruisers and LOS ANGELES class and OHIO class submarines. Soil at the 218-E-12B burial ground is a typical mix of sandy-gravel, sand, and gravelly sand found in the Hanford Formation which underlies the burial ground. The soil is dry with a moisture content of less than 6% by weight, well drained, slightly alkaline with a pH of 8.2, and low in chlorides at 0.08 milligram equivalents per 100 grams soil or about 30 parts per million (NFESC 1993). Soil resistivity at the 218-E-12B burial ground is high, measured as greater than 30,000 ohm-cm. (NFESC, 1993). These conditions, coupled with the average rainfall of 6.3 inches per year are considered beneficial for minimizing corrosion.

The geology and hydrology under the 218-E-12B burial ground are described in detail in Estimation of the Release and Migration of Lead through Soils and Groundwater at the Hanford Site 218-E-12B Burial Ground (PNL, 1992). In general, groundwater occurs under the burial ground in both unconfined and confined aquifers, with the confined (deeper) aquifers bounded above by basalt layers and the unconfined (uppermost) aquifer lying at the interface between the Hanford Formation and the underlying bedrock Miocene basalts. The depth to the uppermost aquifer under the burial ground is approximately 200 feet from site surface and approximately 150 feet from the floor of the current excavation for reactor compartment disposal.

The unconfined aquifer receives little, if any, recharge directly from precipitation that falls on vegetated areas of the Hanford site because of a high rate of evapotranspiration from native soil and vegetation. Surface precipitation may contribute recharge where soils are coarse textured and bare of vegetation (PNL, 1994b). Recharge rates of 0.5 cm/yr and 5 cm/yr have been used at the Hanford Site to model recharge to the unconfined aquifer from the current arid climate and potentially wetter conditions, respectively, assuming no artificial surface barriers (DOE, 1987, DOE, 1989). These recharge rates have been applied specifically to the 218-E-12B burial ground for modeling the leaching of constituents from wastes (PNL, 1992, PNL, 1994a). Actual recharge at 218-E-12B, after closure, may be even lower for a substantial period of time due to the placement of an engineered cover which will result in over 5 meters of soil between the buried reactor compartments and the site surface.

Groundwater modeling conducted by Pacific Northwest Laboratory for the 218-E-12B burial ground (PNL, 1992, PNL, 1994a) suggests that under current climate conditions, in a natural state, the unconfined aquifer will recede southward and not be present under the burial ground. As artificial groundwater discharges in the area surrounding the 218-E-12B burial ground have diminished, aquifer wells adjacent to Trench 94 have been frequently dry.

Hanford formation sediments underlying the 218-E-12B burial ground exhibited a strong tendency to adsorb (immobilize) nickel and nickel radionuclides from groundwater in site specific testing (PNL, 1994a). Nickel solubility was also experimentally determined. Predicted migration times for nickel and nickel-59 from the burial ground to the aquifer varied from 800,000 years for the current climate down to 66,000 years for a postulated wetter condition modeled in which 10 times more water (recharge) is assumed to pass through the burial site than under the current climate condition.

3.3 Corrosion

High strength (HS/HT) carbon steel and very high tensile strength nickel alloyed (HY-80) steel typically form the exterior of reactor compartment disposal packages. Inconel Alloy 600 (a nickel-iron-chromium alloy) is present inside the reactor vessel as the reactor vessel internal structure. Stainless steels such as CRES 304 can also be found inside the disposal package. Site specific studies have been accomplished to determine the performance of reactor compartment disposal packages at the 218-E-12B burial ground. These studies showed that corrosion rates for carbon steels in the soil would be low, with an expected average general corrosion rate of 0.0002 inch per year and a corresponding maximum general corrosion rate of 0.0006 inch per year (DOE, 1992).

The actual general corrosion rates for compartment structure are expected to be less than these predictions. The studies were based on test data for open hearth carbon steel which is somewhat less corrosion resistant than the HY-80 and high strength carbon steel that forms the exterior of reactor compartments and much less corrosion resistant than the Inconel A600 alloy (or CRES 304).

The general corrosion rates for carbon steel at the 218-E-12B burial ground were based on a comparison to actual test data from underground storage tanks exhumed at the Hanford Site as well as available data from National Institute of Standards (NIST) test sites with soil conditions approximating those at Hanford. Pitting rates developed in this manner were converted to general corrosion rates by the use of a conservative conversion factor (DOE, 1992).

Upper limit corrosion rates expressed in milligrams of metal alloy weight loss per square decimeter of surface per year for CRES 304 and A600 Inconel alloys present in reactor compartments, were also estimated for the 218-E-12B burial ground (NFESC, 1993). These corrosion rates are as follows: for CRES 304 - 0.02 milligrams per square decimeter per year, and for Inconel Alloy 600 alloy - 0.01 milligrams per square decimeter per year.

3.4 Performance of Reactor Compartments

Based on the above corrosion rates, Table B-2 outlines the expected performance of a reactor compartment when buried at the 218-E-12B burial ground with respect to personnel access. Structural information and corrosion rates are summarized from previous discussions and used to estimate the time required for access to be gained inside structures as a result of corrosion. Soil pressure exerted on the disposal package exterior is also considered. From Table B-2 it can be seen that access inside the reactor compartment and to the more highly activated structure will require very long periods of time.

> Note: The term "access" is used in this evaluation to denote the physical entering of a space or area by a person's entire body (not just extremities). Access times provided in this section describe the time required for corrosion to allow access as defined above. These times do not imply that structure being accessed or structure through which access is gained is unrecognizable from surrounding soil or dispersible in surrounding soil. Access times also do not imply that a radiation dose exceeding the basis levels for the waste classification method of Title 10 "Energy" of the Code of Federal Regulations, Part 61 (10CFR61) will result from a person entering a space or area at the time provided (i.e. 500 mrem/yr for an intruder and 25 mrem/yr for the environment (NRC, 1982)). Radiation exposure rates associated

with accessing selected reactor compartment structures are discussed in section 3.5. Intruder and migration scenarios resulting in potential radiation dose are discussed in section 3.6.

	Personnel Access to Reactor Compartment	Personnel Access (entire body) to Reactor Vessel Internal Structure	Reactor Vessel Internal Structure
Limiting Barrier	Submarine End Bulkheads	Combination of Reactor Vessel and surrounding tank structure	NA
Thickness	0.75 inch	~ 1/2 foot	NA
Expected Corrosion Rate	0.0002 inch/year	0.0002 inch/year	NA
Expected Time to Access:	~2,000 years	~ 30,000 years	NA
Maximum Corrosion Rate	0.0006 inch/year	0.0006 inch/year	0.02 milligrams metal loss per square decimeter per year
Minimum Time to Access	~600 years	~ 10,000 years	>10,000,000 years (for complete corrosion)

Table B-2 Reactor Compartment Disposal Package Performance

For access to the reactor vessel internal structure, the limiting case considers both access from the inside of the reactor compartment once the endplates have been breached and access directly through the ship's hull under the reactor vessel. Breach of the endplates does not immediately provide access to the interior of the reactor compartment since a secured hatch would have to forcibly opened. However, no credit is taken in Table B-2 for the delaying effect of this hatch on access to the reactor compartment. Inside the reactor compartment, the reactor vessel internal structure is enclosed by a combination of the reactor vessel and a surrounding tank structure providing a series of nested metal structures. For access to the inside of the reactor vessel, corrosion is modeled as occurring in series through these nested structures from the outside to the inside of the reactor vessel.

For the corrosion life of the reactor vessel internal structure, this structure is modeled as a 0.5 inch thick plate with a 2 cubic meter volume. This produces a conservative surface area to volume ratio as the actual thickness and overall volume of this structure varies but is typically greater. The corrosion rate for the reactor vessel internal structure presented in Table B-2 reflects the occasional use of CRES 304 alloy vice the typical Inconel Alloy 600 which corrodes at a lower rate. The greater than 10,000,000 year period for complete corrosion of the reactor vessel internal structure is conservatively based on the CRES 304 corrosion rate multiplied by a factor of 10.

From Table B-2, greater than 10,000,000 years would be required to fully corrode the reactor vessel internal structure. Nearly all of the long-lived radioactivity in the reactor vessel internal structure will have decayed within the metal matrix before it is made available for migration by the extremely slow process of corrosion. Table B-3 provides an illustration of how little of the original inventory of long lived radionuclides could be released during the first 10,000 years of corrosion and over the entire period of corrosion.

3.5 Radiation Exposure

External radiation levels for reactor compartment disposal packages are essentially the result of Cobalt-60 activity contained within the reactor plant. This activity will decay by a factor of 2 every 5.3 years, thus in about 50 years, external radiation levels would be negligible at less than 0.1 mrem/hr on contact. Correspondingly, internal compartment radiation levels would be negligible at less than 0.1 mrem/hr and would remain low until the reactor vessel corrodes substantially exposing the reactor vessel internal structure and thus allowing exposure to gamma radiation from structural material containing niobium-94 inside the vessel.

Close proximity, and one meter distant radiation levels, have been estimated for a reactor vessel internal structure in a bare (exposed) condition and under fully corroded conditions representing the long term consequence of disposal by burial. These radiation levels were based on a 500 year decay period from the time of disposal. For exposed reactor vessel internal structure at 500 years, the radiation level would be a maximum of 11 mrem/hr at 1 meter. For a reactor vessel internal structure assumed to be completely reduced into a pile of corrosion products at 500 years, the radiation levels would be a maximum of 36 mrem/hr at 1 meter from this pile of corrosion products.

Radionuclide	Percentage of initial radionuclide inventory released during the first 10,000 years of corrosion	Percentage of initial radionuclide inventory ever released by corrosion
nickel-63	< 0.003%	<0.003%
carbon-14	<0.1%	<0.2%
niobium-94	<0.2%	<0.4%
nickel-59	<0.2%	<2%
technetium-99	<0.2%	<6%
Combined long lived radionuclides	<0.005%	<0.02%

Table B-3 Activity Released from Reactor Vessel Internal Structure via Corrosion

Table Note:

The 10,000 year period is provided for perspective. Corrosion will not likely initiate until the reactor vessel internal structure is exposed at ~ 10,000-30,000 years.

Different types of reactor vessel internal structures and varying operating times on these structures can be found among the reactor compartment classes considered. Maximum radiation levels presented are based on the combination of structure and operating time that results in bounding radiation levels for all of these classes.

95% of the radiation emitted from the reactor vessel internal structure at 500 years is from niobium-94 which produces gamma radiation with an activity half-life of 20,300 years. The remainder is mainly from nickel-59, which produces lower energy gamma/X-ray radiation with an activity half-life of 75,000 years. At 10,000 years, the minimum time predicted for corrosion processes to allow for whole body access to the reactor vessel internal structure, about 90% of this radiation would still be from niobium-94.

A 500 year decay period is overly conservative when considering the length of time required for corrosion processes at the Hanford Site to bring the reactor vessel internal structure into the exposed and corroded state. From Table B-2, a minimum decay period of greater than 10,000 years and an expected decay period of greater than 30,000 years would occur before the reactor vessel internal structure would potentially be exposed. Consequently, based on the minimum decay period of greater than 10,000 years, the resulting radiation levels at 1 meter would be reduced from the 500 year based 11 mrem/hr to about 8 mrem/hr as a maximum. Based on the expected decay period of over 30,000 years, the resulting radiation levels at 1 meter would be reduced from the 500 year based 11 mrem/hr to about 4 mrem/hr as an expected value.

By the time metallic debris surrounding the reactor vessel internal structure is transported away from the disposal site by corrosion and dissolution into groundwater, substantial activity decay would occur in the reactor vessel internal structure. The slow corrosion rate of the reactor vessel internal structure itself severely limits the amount of activity in this structure that could be released to the environment (e.g. less than 0.02% of total activity, less than 0.4% of niobium-94 activity, and less than 2% of nickel-59 activity, per Table B-3). Even these small percentages of the original reactor vessel internal structure's activity would not be found at any one time in the soil due to decay occurring both in the soil and in the structure as the slow corrosion process releases radionuclides.

The metal alloys of the reactor vessel internal structure are hard, difficult to machine or drill, and not prone to mechanical separation into the soil. The slow corrosion rate of the reactor vessel internal structure severely limits the amount of activity that could be released through corrosion. However, it is unrealistic to assume that a pile of corrosion products could remain exposed and undiluted in soil during and after the greater than 10 million year corrosion period predicted for the reactor vessel internal structure at the Hanford Site 218-E-12B burial ground. In any case, most internal activity in the structure would have decayed before a fraction of the structure could corrode. A very conservative very long term exposure scenario would be to assume that (1) over the greater than 10 million year corrosion life of the reactor vessel internal structure, 1% of niobium-94 and 5% of the nickel-59 activity in the reactor vessel internal structure has been released to the surrounding soil as corrosion products indistinguishable from soil and (2) that this released activity has mixed within a small volume of soil (a 10 by 10 by 10 foot box) and not decayed. The soil volume chosen is roughly 4-5 times the envelope volume of typical reactor vessel internal structure. The resulting radiation levels at 1 meter from the soil would be less than 0.5 mrem/hr. This does not account for the effect of residual metallic elements in the soil, which would add extra shielding benefits.

Table B-4 presents a summary of reactor compartment performance and resulting radiation levels associated with accessing the reactor vessel internal structure.

Minimum corrosion time for access to the reactor vessel internal structure (Table B-2)	Minimum predicted time for complete corrosion of the reactor vessel internal structure (Table B-2)	Percentage of initial radionuclide inventory released during the first 10,000 years of reactor vessel internal structure corrosion (Table B-3)	Percentage of initial radionuclide inventory released by the complete corrosion of the reactor vessel internal structure (Table B-3)	External Dose rate for reactor vessel internal structure when accessible (section 2.5)	External Dose rate for fully corroded reactor vessel internal structure in soil (section 2.5)
~ 10,000 yrs	>1.0 E +7 yrs	<0.005%	<0.02%	~ 8 mrem/hr at 1 meter (maximum) ~ 4 mrem/hr at 1 meter (expected)	< 0.5 mrem/hr at 1 meter

Table B-4 Reactor Compartment Evaluation Summary

3.6 Comparison of Reactor Compartment Disposal to Criteria/Assumptions Used in NRC Exposure Evaluations

3.6.1 Deliberate Intrusion

In the Final Environmental Impact Statement on 10CFR61, Volume 1 (NRC, 1982), the NRC stated that deliberate intrusion into a disposal facility cannot reasonably be protected against and is thus not considered further by the NRC in the development of 10CFR61. Nevertheless, upon closure of the 218-E-12B Low Level Waste Burial Ground at Hanford, WA, the reactor compartments would be buried more than 5 meters deep with an engineered cover placed over the buried compartments. The robust nature of the compartments and their durability in combination with the manner of their burial would discourage deliberate intrusion.

3.6.2 Inadvertent Intrusion

The NRC has based the waste classification method of 10CFR61 on assumptions of agricultural and construction related intruder scenarios where the activity from Class C wastes is, after 500 years, indistinguishably mixed with soil so that an intruder would not know that a waste site was being intruded upon. Limits for activity concentration in the waste were determined based on a 500 mrem/yr maximum exposure from these scenarios (NRC, 1982).

In 10CFR61 Part 56(b), waste stability is cited as a factor in limiting exposure to an inadvertent intruder, since the stability provides a recognizable and non-dispersible waste. The robust nature of the compartments and their durability in combination with the manner and depth of their burial at Hanford would prevent inadvertent intrusion involving the type of agricultural and construction scenarios evaluated by the NRC. Significant activity from the compartments would not be brought inadvertently upwards into the food chain at the land surface. From Table B-2, the reactor compartment, reactor vessel, reactor plant components and the reactor vessel internal structure itself will provide for physical remnants very distinguishable from surrounding soils for the foreseeable future. The reactor vessel internal structure disperses very slowly due to its long corrosion life. From Table B-3, the reactor vessel internal structure would release less than 0.02% of its activity to the soil and the structure itself would also remain essentially intact and distinguishable from soil for the foreseeable future.

Consequently, the only realistic intruder scenario that should be considered for disposal of reactor compartments is the intruder well penetrating through the 218-E-12B burial ground with a less probable hypothetical scenario wherein a person inadvertently manages to exhume a reactor compartment and enters it or inadvertently exhumes remnants of this reactor compartment at a very long time in the future.

3.6.2.1 Intruder Well

In the 10CFR61 Environmental Impact Statement (NRC, 1982), an intruder well scenario was evaluated for the current "no action" case of pre-10CFR61 disposal practices with a resulting maximum dose of about 11 mrem/yr to the thyroid from iodine-129 and a dose of less than 0.1 mrem/yr to the whole body. Iodine-129 Class-C limit based activity concentration fractions for reactor compartment reactor vessel internal structures are less than 0.000001 and thus thyroid dose would not be of concern. The remaining whole body dose as evaluated by the NRC is already well below the 500 mrem/yr basis for intruder scenarios or even the 25 mrem/yr basis for protection of the environment via migration pathways.

For buried reactor compartments, the long lived radionuclide inventory of niobium-94, nickel-63, and nickel-59 that control the waste classification are locked within the metal matrix of activated materials that will take greater than 10,000,000 years to fully corrode. A well drilled through the burial site would contact and be obstructed by high strength steels from the disposal package for thousands of years and from the reactor vessel for tens of thousand of years. This same well would be obstructed by non-activated CRES 304 and Inconel Alloy 600 from the reactor plant for as long as the life of the reactor vessel internal structure. In addition, Inconel Alloy 600 tends to work harden and is difficult to machine.

If the intruder well stops at the depth of the obstruction (the buried waste), the well should be dry. If the well continues to the bedrock below, the well should be dry under the current climate conditions at Hanford and if not, niobium-94 and nickel-59 should take a very long time to migrate to this depth.

Pacific Northwest Laboratory estimated the migration of nickel through soils and groundwater at the 218-E-12B burial ground from a group of 120 large metal components representing reactor compartments. A current climate condition was modeled and a postulated wetter condition with a recharge rate set at 10 times the rate used to model the present climate. Groundwater modeling conducted as part of this work suggests that under current climate conditions, in a natural state, the aquifer under the 218-E-12B burial ground will recede southward and not be present under

the burial ground. Even under a postulated wetter condition modeled with a site recharge rate set at 10 times the rate used to model the present climate, the water table under the burial ground is still predicted to be about 40 meters (130 feet) below the bottom of the burial excavation.

Pacific Northwest Laboratory predicted very long times of over 66,000 years under the postulated wetter condition modeled and 800,000 years under the current climate condition for nickel-59 released from buried disposal packages to reach a well drilled 100 meters (330 feet) downstream of the site (PNL, 1994a). Transport time from the disposal packages to the bedrock directly under the disposal site occupied over 99% of these predicted times due to adsorption of nickel into the unsaturated soil. Nickel-63 decayed en-route and never reached an aquifer. Thus, nickel-63 from reactor compartment disposal packages would likely never enter an intruder well and nickel-59 would take 66,000 years, a very long time, to enter such a well.

An estimate of the time required for niobium-94 to migrate to the aquifer under the burial site can be made by use of retardation factors provided by the 10CFR61 EIS (NRC, 1982). Retardation factors account for the effects of adsorption in soil which delays the migration of radionuclides through the soil. The retardation factors provided in the NRC EIS essentially represent the relative time required for radionuclides to travel a given distance through soil compared to the time required for groundwater to travel the same distance. The higher the retardation factor, the slower the radionuclide moves. Niobium-94 retardation factors provided by the NRC are at least twice as large as for nickel-59, therefore, niobium-94 should take twice as long to transit a given depth of soil as for nickel-59. This is conservative in that niobium-94 concentration in reactor vessel internal structures is 2 orders of magnitude below nickel-59 concentration and is contained within the same corrosion resistant metal alloys as nickel-59. This would tend to increase transport times for niobium even further. The release rate of niobium-94 in curies per year per compartment would be 2 orders of magnitude lower than for nickel-59 initially, decreasing even further relative to nickel-59 as niobium-94 decays 3 times faster. Even though ingestion of niobium-94 at a given concentration would likely produce a higher exposure dose than ingestion of an equivalent concentration of nickel-59, this effect should be overcome by the lower release rate and longer migration time.

Pacific Northwest Laboratory (PNL, 1994a) predicted doses that would result under a maximally exposed individual scenario involving a person who uses water from an aquifer well 100 meters (330 feet) downstream of the burial site for all personal food production and consumption needs. This work, which used the GENII dose model (PNL, 1988), produced a dose from nickel-59 ingestion of less than 0.001 mrem/yr after a 66,000 year minimum migration time. A group of 120 large metal components representing reactor compartments was assumed to be buried at the site. Considering the placement of 220 reactor compartments at the burial site, niobium-94, and the location of the intruder well, this dose would not increase to the 500 mrem/yr intruder limit or even to the 25 mrem/yr release to the environment performance standard of Subpart C of 10CFR61.

3.6.2.2 Exhumation

External radiation levels on reactor compartment disposal packages are essentially the result of Cobalt-60 activity contained within the reactor compartments which will decay by a factor of 2 every 5.27 years. Thus, in about 50 years, external radiation levels would be negligible at less than 0.1 mrem/hr even on contact. Correspondingly, radiation levels inside the reactor compartment would be negligible at less than 0.1 mrem/hr and intruder exposure would remain

very low until about 10,000 to 30,000 years have elapsed (Table B-2) at which point the reactor vessel has corroded sufficiently to allow intruder access (whole body) through the reactor vessel to the reactor vessel internal structure.

Based on a minimum 10,000 year access time for the reactor vessel internal structure, the maximum radiation level at 1 meter from an exposed reactor vessel internal structure would be 8 mrem/hr. At this radiation level, the intruder would have to spend 2.5 days at 1 meter from this structure to reach a 500 mrem/yr exposure.

Based on an expected 30,000 year access time for the reactor vessel internal structure, the expected radiation level at 1 meter from an exposed reactor vessel internal structure would be 4 mrem/hr. At this radiation level, the intruder would have to spend 5 days at 1 meter from this structure to reach a 500 mrem/yr exposure. However, direct or very close proximity contact with reactor vessel internal structure over a period of time necessary to reach the 500 mrem/yr basis is not considered plausible because the reactor vessel internal structure would likely never be actually exposed and unshielded to an inadvertent intruder.

Over the 10,000 to 30,000 year period required for corrosion to allow entire body access to the reactor vessel internal structure, the reactor compartment hull, being thinner than the reactor vessel, subject to external soil pressure, and supporting the compartment internals, would likely have collapsed downward bringing the compartment contents down on top of the reactor vessel. Lead shielding plates, corrosion resistant steels such as CRES 304 and Inconel Alloy 600 that comprise the reactor plant inside the compartment, remnant heavy steel framing from the hull, corrosion products, and polyethylene shielding from the reactor vessel and the remainder of the compartment would cover the reactor vessel remnant and the reactor vessel internal structure inside hindering access and providing shielding not considered in this analysis.

Greater than 100 tons of lead shielding is present in reactor compartment disposal packages with some of this lead being in a position to fall over the pressure vessel upon compartment collapse. Due to the very low solubility of lead predicted for the 218-E-12B burial ground environment (PNL, 1992) some shielding lead in reactor compartment disposal packages will continue to be present for perhaps as long as remnants of the reactor vessel internal structure remain. On average, over 90 metric tons (100 tons) of CRES 304 and/or Inconel Alloy 600 typically form the reactor plant which occupies the reactor compartment along with the reactor vessel. This material shares the same low corrosion rate discussed in section 2.3 as for the reactor vessel internal structure and remnants will last as long.

The volume of lead and corrosion resistant materials in the compartment is much greater than that of the reactor vessel internal structure. The volume of metal directly above the reactor vessel internal structure up to the top of the reactor compartment disposal package is typically much greater than that of the reactor vessel internal structure. Collapse of the compartment over the reactor vessel internal structure and the filling of void spaces remaining within the remnant compartment with soil should completely cover the reactor vessel internal structure producing a difficult to penetrate mound of debris that would provide some shielding benefit.

Eventually corrosion processes will remove the less corrosion resistant materials from the debris mound. Over the greater than 10 million years required to fully corrode the reactor vessel internal structure, less than 0.02% of total activity will be released to the soil due to decay. Correspondingly, less than 0.4% of niobium-94 activity and less than 2% of nickel-59 activity will be released to the soil. If this activity is very conservatively assumed to be released all at once into

a cubic volume of soil 3 meters (10 feet) to a side or 27 cubic meters (1000 cubic feet) total, resulting radiation levels at 1 meter from this volume of soil would be less than 0.5 mrem/hr not accounting for self shielding effects in the soil resulting from residual metallic elements adsorbed onto soil particles. However, this exposure will not actually ever occur because the activity that is released into the soil is released so slowly that only a fraction of the 0.02% total released would be present at any one time in the soil. Ingestion of soil by the intruder sufficient to result in a significant intruder dose is not considered plausible due to the dilution provided by clean soil and the mass of corrosion products resulting from corrosion of the reactor compartment and the slow release of a small amount of activity over a long time.

Intruder doses under the scenario discussed above would not likely reach the 500 mrem/yr limit used by the NRC to develop the 10CFR61 waste classification method. Intruder dose for the intruder well scenario would also not reach the 500 mrem/yr limit. It should be noted that the long times required for radionuclides to be released into the soil from the reactor vessel internal structure are beyond the accepted time scale of human civilization on earth.

3.6.2.3 Groundwater

The only plausible exposure scenario to the general public from buried reactor compartments would involve the groundwater pathway tapped by a well. The depth and manner of burial of the compartments coupled with the free-draining arid nature of the Hanford Soils and the slow release of activity from the compartments inhibit the migration of activity upward from the compartments to the land surface.

As discussed previously in the intruder well evaluation, Pacific Northwest Laboratory (PNL, 1994a) predicted very long times of over 800,000 years under the current climate condition and over 66,000 years under the postulated wetter condition modeled for nickel-59 released from buried reactor compartment disposal packages to reach a well drilled 100 meters (330 feet) downstream of the burial site. Nickel-63 decayed en-route and never reached the site aquifer or a downstream well. As a result, "maximally exposed" individual doses calculated for a person using the 100 meter (330 feet) downstream well were less than 0.001 mrem/yr based on nickel-59 ingestion alone.

Other radionuclides are not present in sufficient quantity in the reactor compartments to add any significant dose under the groundwater migration pathway. Thus, maximally exposed individual doses for the groundwater pathway would not reach the 25 mrem/yr "release to the environment" performance standard of Subpart C of 10CFR61.

3.7 Compliance with 10CFR61 Subpart C Performance Objectives

3.7.1 Part 61.41 Protection of the Public from Releases of Radioactivity

Releases to the general environment shall not to exceed 25 mrem/yr to the whole body, 75 mrem/yr to the thyroid, and 25 mrem/yr to any other organ equivalent dose to the public (10CFR61.41)

As discussed in section 3.6.2, the only plausible exposure scenario to the general public from buried reactor compartments would involve the groundwater pathway tapped by a well. This type of pathway would not result in exposure doses exceeding 25 mrem/yr.

3.7.2 Part 61.42 Protection of Individuals from Inadvertent Intrusion

The 10CFR61 EIS (NRC 1982) indicates that the NRC in developing the waste classification method of 10CFR61 set a maximum 500 mrem/yr equivalent intruder dose as the basis for determining appropriate limits for activity.

As discussed in section 3.6 and section parts 3.6.1. and 3.6.2., the only plausible intruder scenarios for disposal of reactor compartments at the Hanford Site 218-E-12B burial ground involve an intruder well and a less probable exhumation of the compartment. Exposure doses from the intruder well would not reach 500 mrem/yr. Exposure dose from the exhumation scenario would not likely reach 500 mrem/yr. The depth and manner of burial of the reactor compartments, and the robust, long lived nature of the compartments, inhibits intrusion and limits exposure.

3.7.3 Part 61.43 Protection of Individuals During Disposal Site Operations

The Hanford Site, a Department of Energy managed facility, has adequate procedures and controls to accomplish this purpose. The reactor compartment disposal packages typically would have exterior radiation levels of less than 1 mrem/hr on contact at the time of disposal. Areas with higher radiation levels would be found under the compartment and would have standard radiation markings. Within 50 years of disposal, all exterior radiation levels would decay to negligible levels less than 0.1 mrem/hr.

3.7.4 Part 61.44 Stability of the Disposal Site After Closure

The Hanford Site has adequate procedures and controls to accomplish this purpose. The reactor compartments are strong and durable and would not cause any significant subsidence at the burial site surface upon burial and for at least 600 years afterwards. An engineered cover would be placed over the disposal site upon closure to add stability and limit moisture influx.

4. CONCLUSIONS

Disposal of Naval Reactor Compartments at the 218-E-12B Low Level Waste Burial Ground at Hanford, WA meets the performance objectives for intruder and environmental protection from 10CFR61. The requirements of Department of Energy Order 5820.2A "Radioactive Waste Management" (DOE, 1988) provide a similar level of protection equivalent to the NRC regulations of 10CFR61 and in many cases mirror the NRC regulations. Consequently, disposal of reactor compartments at the 218-E-12B burial ground, Hanford, WA is also consistent with the DOE order.

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REFERENCES (Continued)

10CFR61	Code of Federal Regulations Title 10 "Energy" Part 61.
10CFR61.41	Code of Federal Regulations Title 10 "Energy" Part 61.41.